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## Review article

## Folk to functional: An explorative overview of rice-based fermented foods and beverages in India

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## ABSTRACT

Fermented foods share an integral part of age-old wisdom from ancient Indian civilization. Over the generations, this pioneering practice of food fermentation has expanded and improved to preserve and fortify the available food resources, particularly to meet the hidden hunger. India, being the second largest producer of rice, has a great history of traditional rice-based fermented foods with different tastes and textures linked with cultural diversity and mostly prepared by rural women following village art techniques. Some of them have been scientifically investigated and it has been revealed that microflora in natural or starter culture plays imperative roles to bio-embolden the rice with varieties of health promoting macronutrients and micronutrients, phytochemicals, and other functional components during fermentation. In this review, some explorative information on traditional rice-based foods and beverages has been assembled to illustrate the global interest in Indian food heritage and their functional aspects. The review also deals with the preparation of raw materials, traditional processing, composition, and ethno-medicinal importance of each food to encourage entrepreneurs to develop large-scale production to meet the growing market demand of functional foods.

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## 1. Introduction

On the Indian subcontinent, fermented foods and beverages are an integral part of cultural heritage, even today. These have been developed throughout the history of human civilization for sustained nutrition and food preservation [1,2]. Fermentation leads to changes in appearance of food characterized by quite different properties and uses. Ancient people adopted different preservation methods to store excess foods of plant and animal origin, particularly those which are seasonal and have a short lifespan (perishable). On this basis, it is presumed that fermented foods probably originated during 7,000–8,000 BC in the areas of Indus Valley [3]. It is evident from the annals of the Harappan civilization (Vedic period) that people used different clay pots for preparing fermented foods and drinks [4]. Fermented milk products, alcoholic beverages from fruits and cereal grains, and leavened breads were very popular among the early civilization in the Middle East and in the Indus Valley and later among the Egyptians, Greeks, and

Romans. The health-beneficial effects of fermented food were first advocated as far back as 76 AD by the Roman historian Pliny, who mentioned the use of fermented milk for treating gastrointestinal infections. In the late 1700s, Lavoisier revealed the chemical basis of sugar transformation. Around 1850, the great French chemist, Pasteur, discovered the biological basis of fermentation and identified the particular role of microbes that initiate and continue the fermentation process [5]. In the early 1900s, Tissier, a French pediatrician, proposed that bifidobacteria in food could be effective in preventing infections in infants [6]. This health-beneficial concept of fermented foods has matured through extensive scientific interventions, particularly over the past 2 decades, thereby increasing consumer awareness of the functional basis for ingesting such traditional foods in relation to health promotion and disease prevention [7–10].

Currently, > 5,000 different fermented foods are consumed by mankind worldwide, many of which are ethnic and produced in small quantities to meet the needs of groups in a particular region. Traditional fermented foods are defined as foods produced by native people using their ancestral knowledge and artisanal techniques from locally available raw materials of plant or animal sources. These are prepared either naturally or by adding starter

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culture(s) containing functional microorganisms which modify the substrates biochemically and organoleptically into edible products that are culturally and socially acceptable to consumers [11]. The ethnic food fermentation process was modified continuously through the propagation of traditional knowledge and experiences from one generation to the next, particularly keeping in mind improved sensory qualities and safety. The idea of fermented food preparation also expanded with diverse locally available substrates including grains, vegetables, milk, fish, and meat products [12]. The rural folk are found to prefer the fermented foods over the unfermented, because of their pleasant taste, texture, and color [13].

Traditional fermented food preparation is one of the oldest biotechnological processes around the world in which microorganisms play a crucial role in improvement of sensory characteristics, bioenrichment, health promoting attributes, and preservation of foods. Fermentation helps to reduce nondigestible carbohydrates, enriches the pool of essential amino acids, vitamins, and minerals, and increases the overall quality, digestibility, taste, and aroma of the food [14,15]. This extraordinary benefit of fermented food is helpful to maintain the healthy composition of intestinal microbiota that are essential for protection from various diseases and to maintain physiological homeostasis and the gut–brain relationship of the host. From this point of view, fermented food is designated as “naturally fortified functional food”. The term “functional food” was first introduced in Japan in the mid-1970s. It refers to processed foods containing physiologically active ingredients that aid specific bodily functions beyond basic nutrition [16,17]. A recently proposed working definition of functional food is: “food that can be satisfactorily demonstrated to affect beneficially one or more target functions in the body, beyond additional nutritional effect, in a way relevant to an improved state of health and wellbeing and/or reduction of risk of disease” [18,19].

Global interest in cereal-based fermented products is increasing due to low fat/cholesterol, high minerals, dietary fibers, and phytochemicals content [15]. Beyond the basic nutrients, cereal-based fermented food confers several health promoting attributes, as it contains edible beneficial microbes, also called probiotics, fermentable sugars (of microbial and food origin, i.e., prebiotics), and digestive aids such as a group of microbe-derived hydrolytic enzymes, etc. In addition, multistrain or multispecies probiotics may provide greater beneficial effects than monostrain cultures. The synergistic actions of these exogenous microbiota create a sociable environment for commensals (native colonizing organisms), prevent the growth of otherwise enteropathogens, are beneficial for digestion and absorption, produced different metabolites including short chain fatty acids, especially butyrate, which have a positive effect on epithelial lining of the gastrointestinal tract, enhance mucosal cell differentiation, and this may also promote the immune barrier function of the epithelium, and on peristalsis, which improves transit [20,21]. Cereal components are the natural growth media/carriers for probiotics and have a buffering capacity to protect the organisms in the harsh environment of the intestine [22]. Considering these beneficial effects, the grain-based fermented foods have now become more popular than conventional dairy-based products, particularly in Japan and Europe [23]. The market of nondairy probiotic beverages is expanding, with a projected annual growth rate of 15% (between 2013 and 2015). It is predicted that the market will reach €65 billion by the year 2016 and on this, dairy-based produce accounts for approximately 43% of the market [24].

The art of preparation of different types of dishes from fermented rice or rice-mixed cereal/pulse products is a well-known practice in India. These foods are important components of the diet as staples, adjuncts to staples, condiments, and beverages. In India, diversity of rice-based traditional fermented foods is related

to diversity of ethnicity in each community [25,26]. Rice-containing foods are fermented by a mixed culture of microorganisms by spontaneous fermentation and, in the case of beverages, by adding a starter culture. These are prepared in households or in cottage industries using relatively simple techniques and equipment [26]. In the recent past, there were no verified data on the nutritional, technical, and quality control implications of indigenous rice-based fermented food products in India, the second most populated rice production country in the world. However, in the past 20 years, a number of books and articles dealing with indigenous rice-based fermented beverages and foods have been published. In this context, this review focuses on the unexplored mystery of microbial interplay in rice-based indigenous fermented foods and beverages, and emphasizes the importance of the bioactive functional biomolecules. This will offer ample scope for researching and protecting the traditional knowledge through intellectual property rights and will be helpful for commercialization of these indigenous food products [27].

## 2. Indian perspective of fermented food diversity

The term fermentation is derived from the Latin word *fermentum*, which stands for boiling. It may be defined as any process for the formation of a product by the mass culturing of microorganisms [28]. Fermented food preparation, as mentioned in literary texts, is more than 3,000 years old in India [29]. The Rgveda (1,500 BC) shows that fermentation technology took its first step in connection with the preparation of *soma* juice (alcoholic beverage). There is also another drink, known as *sura* (wine/beer), prepared by fermentation of boiled rice/barley [13]. It is known from different sources that during the post-Vedic period (600 BC to 100 CE) many beverages like *medaka* (spiced rice beer), *prasanna* (spiced barley or wheat beer), *asava* (sugarcane beer), etc., were some of the most popular drinks. Some new recipes for fermentation were also formulated. One such recipe was described in Rasopanisat (RP. XV 251–253). The recipe was: “The best ones among the five classes of bulbous plants with latex are pounded along with the grains of rice of *Kodrava* (*Paspalumscrobiculatum*), and products of plant *madana* (emetic nut) are pasted with whey from water buffalo or cow milk and kept in a closed bowl. The closed vessel is then placed in the sun. The acidic residue thus obtained is *kinva* (yeast)”. Another recipe was *sukta*: a mixture of treacle, honey, fermented rice, water, and whey. This mixture was placed in an earthen pot and the pot then placed on heaps of paddy for 3 nights in the summer season. Another recipe was also known as *kanjika*: boiled millet or barley was used as a base material. Different plants were added into the fermented medium. It could also be prepared by using boiled rice [30].

Native people possessed an immense knowledge on the environment and suitability of plant and animal products as edible and wholesome foods. They understood the functioning of the ecosystem and techniques of using and managing plants and animals [31]. Indigenous food fermentation is an efficient approach for preparation and preservation of food by unknowingly using microorganisms [13,25]. During fermentation, people used very simple and common utensils and locally available ingredients. According to the nature of common plant and animal resources, indigenous fermented foods can be categorized as cereal- and/or pulse-based, vegetables, beverages, wine, milk, and fish- and meat-based products [32]. They are very popular due to their specific organoleptic properties, caloric value, health benefits, and extended shelf life. Apart from own composition, people used the fermentation process for the production of colors/dyes, ingredients as fish bait, animal feed, etc. [11,13].

Even today in India, fermented foods and beverages are taken by people of both of low and high income groups [21]. The traditional

process of preparation is still followed by the specific tribes and castes in different provinces. Some fermented food items are popular as delicious daily dish and propagated even abroad. Figs. 1–3 depicts a unified geographical map of India along with region specific rice-based fermented food and beverage diversity. It is seen that there are four fermented foods hotspots – South India, Himalayan India, East India, and North-East India (Fig. 4).

### 3. Rice: the principal substrate for fermented food and beverages in India

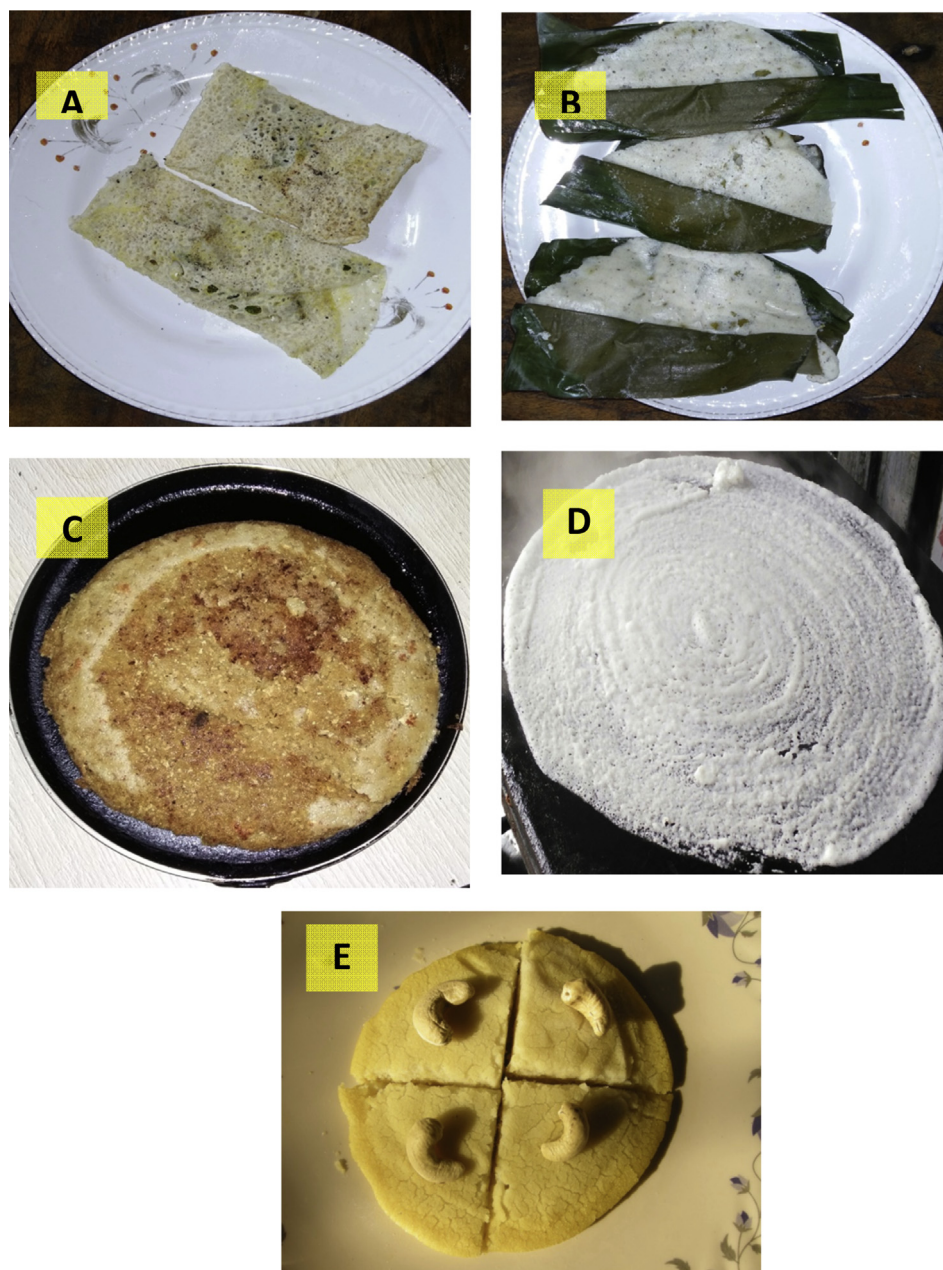
Rice is known as the grain of life, and is synonymous with food for every Indian [33]. It is the staple food for two thirds of the Indian population [34]. It is one of the most important food crops in terms of area, production, and consumer preference. India is the second

largest producer and consumer of rice in the world [35]. Rice production (around 4,000 varieties) crossed the mark of 100 million MTnes in 2011–2012 accounting for 22.81% of global production in that year. The Indians derive 80% of their energy needs from rice, which contains 80% carbohydrates, 7–8% protein, 3% fat, and 3% fiber. The mineral content, starch quality, glycemic index, and antioxidant activity has made rice unique among cereals. Positive qualities of high digestibility of starch, high biological value of amino acids, high content of fatty acids and selenium, and antihypertensive effects have been confirmed scientifically. Rice can, therefore, be described now as a functional food [23,36]. In India, rice has enjoyed a unique status since ancient times because of its nutritional, but also medicinal values. Ancient Indian texts and folklore contain references to the special properties of rice. The great sage, *Parashara*, in the Sanskrit text *Krishni-Parashara*, aptly



Fig. 1. Traditional rice based foods in India. (A) Dosa. (B) Idli. (C) Dhokla. (D) Uttapam. (E) Selroti. (F) Adai and vada.





**Fig. 2.** Traditional rice based *pithas* in India. (A) *Chhuchipatra pitha*. (B) *Enduri pitha*. (C) *Podo pitha* (by courtesy Professor Shantilata Sahoo). (D) *Chakuli pitha*. (E) *Munha pitha* (by courtesy Sikta Sui and Jyoti Prakash Soren).

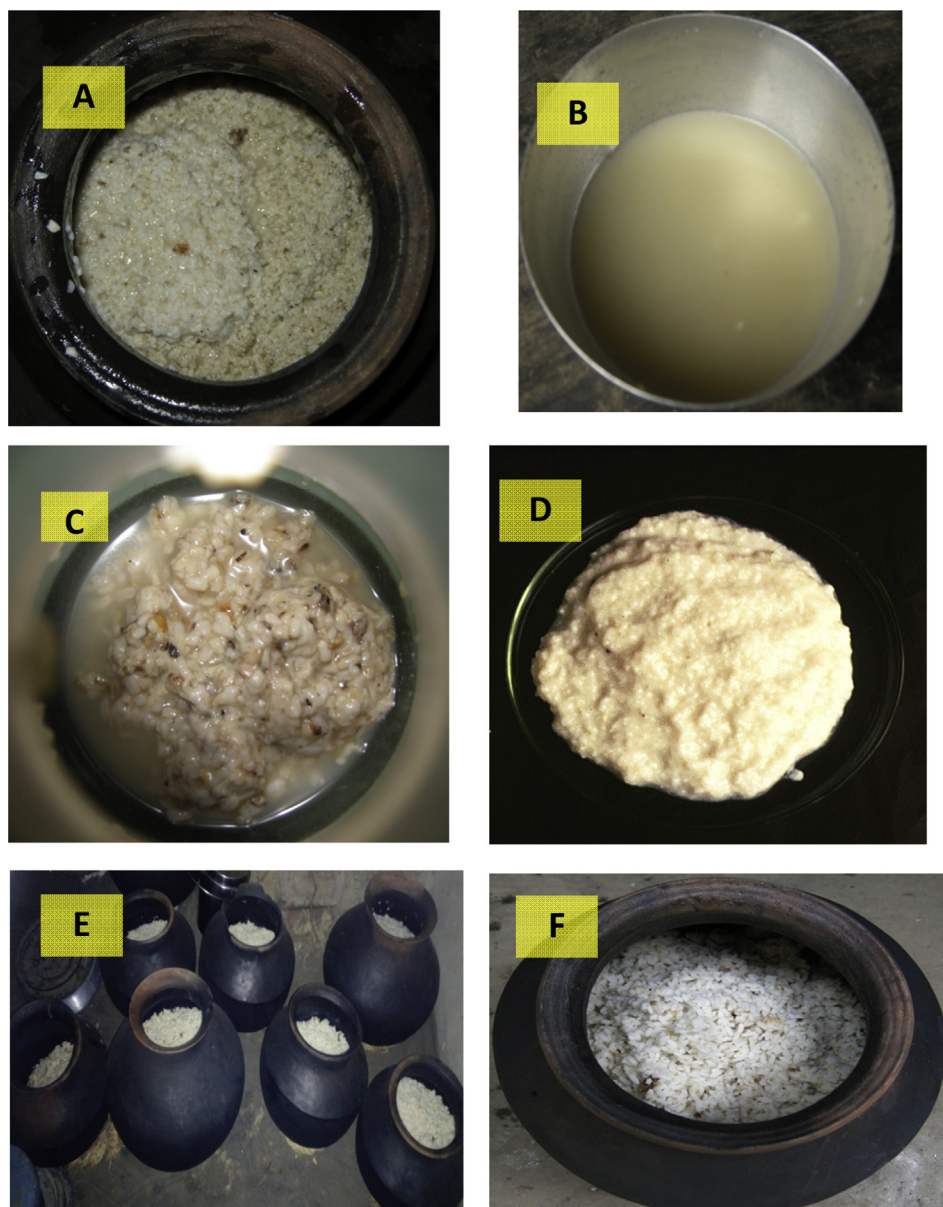
wrote in praise of this food grain, “Rice is vitality, rice is vigor too, and rice indeed is the means of fulfillment of all ends in life. All Gods, demons and human beings subsist on rice”. Ancient Ayurvedic treatises laud Raktashali red rice as a nutritive food and medicine. The medicinal values of other rice varieties, such as Sashtika, Sali, and parched rice, have been documented in the *Charaka Samhita* (700 BC) and the *Susruta Samhita* (400 BC), for the treatment of various ailments [37].

Rice is also used in different forms such as flour, paste, laja (parched rice), boiled, flattened, fried rice, and dried, and as sprouted seedlings [38]. Due to it being the most available and common food resource in the Indian subcontinent, preparation of different types of fermented foods and beverages from rice is a regular practice since time immemorial [39]. The fermented rice-based products play an integral role in social, rituals, and festivals

for almost all Indians [29]. Fermentation enriches the rice, supplements it with different essential amino acids, vitamins, minerals, prebiotics, probiotic organisms, and degrades antinutrients (phytic acid, tannins, and polyphenols). Thus, its nutrition, energy contents, and therapeutic potentialities are increased [38].

#### 4. Microbial diversity associated with rice-based fermentation

Starch-containing cereal-based media favor the growth of ubiquitous groups of microbes [40]. These are mainly derived from nature (natural or spontaneous) or from the addition of a starter culture (controlled fermentation by monoculture or multiculture) [26,41–43]. These microbes secrete different metabolites and enzymes which further encourage their own growth, prevent the



**Fig. 3.** Traditional rice based beverages in India. (A) Rice Jann. (B) Haria. (C) Judima. (D) Bhati jannar (by courtesy Professor J.P. Tamang). (E) Zutho. (F) Unfermented rice.

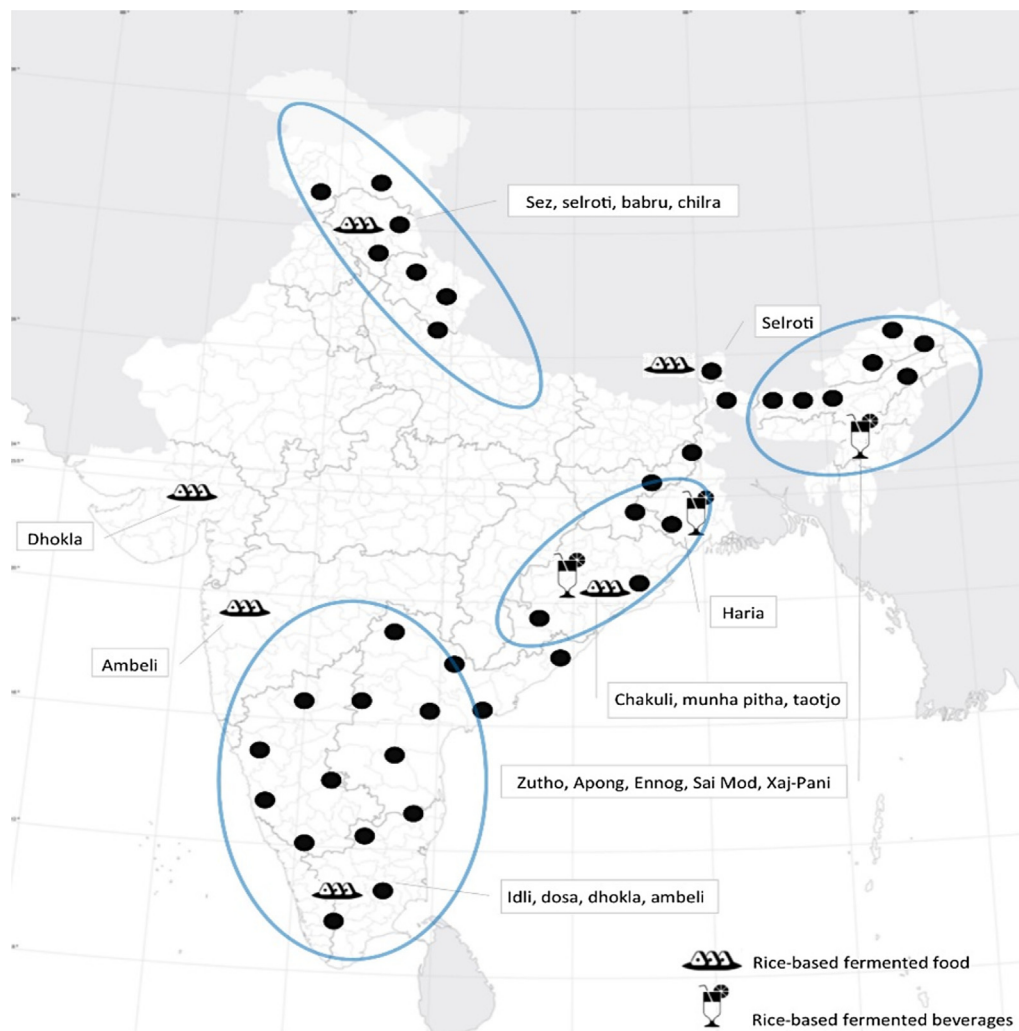
growth of pathogens, and above all, add nutritive and therapeutic potentialities. Among them the most common microorganisms are lactic acid bacteria (LAB), lactobacilli, bifidobacteria, yeasts, and molds [44].

LAB are so named for their production of lactic acid during the fermentation of carbohydrates. LAB do not form a systematically defined group based on evolutionary relationships, they rather belong to a functional group used by food microbiologists. They are harmless and utilized for both good food quality and human welfare [14,44]. In fact, they constitute a group of acid-tolerant (pH 5.0), Gram-positive bacteria with characteristics of being catalase-negative, nonmotile, nonrespiring, and non-spore forming cocci or rods. The following genera are considered to be LAB: *Aerococcus*, *Cornebacterium*, *Enterococcus*, *Lactobacillus*, *Lactococcus*, *Leuconostoc*, *Oenococcus*, *Pediococcus*, *Streptococcus*, *Tetragenococcus*, *Vagococcus*, and *Weissella* [45]. LAB fermentation in cereal-containing foods provides a natural way to concentrate and enhance nutrients (minerals, vitamins, and essential amino acid synthesis) [46], to

destroy undesirable components (antinutrient, mycotoxin, and other endotoxins), to enrich with therapeutic components (phenolics, maltooligomers, prebiotics, probiotics, antioxidants, antimicrobials, and other bioactive substances), and to modify sensory qualities (taste, aroma, texture, consistency, and appearance) of the food [42]. Additionally, these make the food preparation easy (reduced cooking times and lower energy consumption), facilitate preservation from the detrimental effects of spoilage and pathogenic organisms, and enhance product safety [47].

*Lactobacillus* and *Bifidobacterium* constitute the maximum number of lactic acid producing bacteria which are commonly associated with the food fermentation processes. They are non-spore forming, Gram-positive rods, and grow in facultative anaerobic to microaerophilic conditions. Genomes of the lactobacilli range between 1.23 Mb (*Lactobacillus sanfranciscensis*) and 4.91 Mb (*Lactobacillus parakefiri*), with 31.93–57.02% GC content comprising only 73 genes. The LAB group yields a wide range of glycoside hydrolase enzymes which modify host-indigestible plant-derived





**Fig. 4.** Popularity of ethnic rice-based fermented foods and beverages in the specified geographical locations in India.

polysaccharide and oligosaccharide complexes (dietary fibers, glycans, oligosaccharides, resistant starch, cellulose, hemicellulose, xylan, arabinofuran, arabinogalactan, pectins, and gums). They are also able to synthesize antimicrobial substances, amino acids (glutamic and aspartic acids), vitamins, and many other bioactive metabolites [48]. Numerous research groups have established the health benefits of LAB like preventing diarrhea, favoring the lodging of health-beneficial bacteria in the gut, colon regularity, caring of lactose intolerance, reduction in cholesterol, immune stimulatory effects, and even cancer prevention [49,50].

Several groups of filamentous fungi and yeast are also commonly associated with rice-based fermented foods. The yeasts belonging mainly to the genera *Saccharomyces*, *Candida*, *Hansenula*, *Saccharomycopsis*, and molds like *Aspergillus*, *Rhizopus*, *Mucor*, and *Penicillium* participate in this sort of fermentation [15,21]. These strains help with the degradation of starch into maltose and glucose by producing extracellular amylolytic enzymes ( $\alpha$ -amylase and glucoamylase). They also produce carbon dioxide and play a significant role in leavening [44,50]. Yeasts contribute not only to gas production, resulting in good texture, but also to sensory qualities like taste and aroma by producing a group of compounds such as glycosides, esters, fusel alcohols, acids and other compounds. The higher activity of amylases, proteolytic enzymes, levels of B vitamins, and free amino acids attained in yeast-enriched

fermentation suggests that yeast-enriched food develops a positive nitrogen balance. Ethanol is another imperative metabolite of yeast. It serves as a source of calories and prevents the growth of disease- or toxin-producing microorganisms in food products [52].

## 5. Biochemical transformation during rice fermentation

Biochemically, four different types of fermentation processes are known to take place, namely, alcoholic, lactic acid, acetic acid, and alkali fermentation. Alcoholic fermentation results in the production of ethanol by yeast (as in wine and beer). Lactic acid fermentation (homofermentative or heterofermentative) is mainly carried out by lactic acid-producing bacteria (LAB). Under excess aeration, *Acetobacter* produces acetic acid from alcohol. Alkali fermentation occurs in the case of fish and seeds, protein-rich food constituents [25,30].

Rice-based fermentation involves either acidic or alcoholic fermentation or both consecutively. In the beginning, the process includes pretreatment of rice grains, such as soaking, grinding, or boiling, which generally relaxes the compact structure of starch and simultaneously dilutes the contents of antinutrient components. The extended soaking in some food preparations initiates the germination process by activating various hydrolytic enzymes, which relax the starch compactness by exo- and endo-cleaving

**Table 1**  
Microbial profile associated with different rice-based fermented foods and raw ingredients.

Fermented food	Raw materials	Microorganisms involved	References
Idli	Rice ( <i>Oryza sativum</i> ) and black gram dhal ( <i>Phaseolus mungo</i> ) (4:1)	<i>Leuconostoc mesenteroides</i> , <i>Lactobacillus delbrueckii</i> , <i>Lactobacillus fermenti</i> , <i>Lactobacillus lactis</i> , <i>Streptococcus faecalis</i> , <i>Saccharomyces cerevisiae</i> , <i>Pediococcus cerevisiae</i> , <i>Debaryomyces hansenii</i> , <i>Hansenula anomala</i> , <i>Tortilopsis candida</i> , <i>Trichosporon beigeli</i>	[15,44,51,59–60]
Dosa	Rice ( <i>O. sativum</i> ) and black gram dhal ( <i>P. mungo</i> ) (2:1)	<i>L. mesenteroides</i> , <i>S. faecalis</i> , <i>T. candida</i> , <i>L. fermentum</i> , <i>Bacillus amyloliquefaciens</i> , <i>L. lactis</i> , <i>L. delbrueckii</i> , and <i>Lactobacillus plantarum</i> , <i>S. cerevisiae</i> , <i>D. hansenii</i> , <i>T. beigeli</i> , <i>Tortilopsis</i> sp. and <i>Trichosporon pullulans</i>	[15,44,62]
Dhokla	Rice ( <i>O. sativum</i> ) and black gram dhal ( <i>P. mungo</i> ) (4:1)	<i>Tortilopsis</i> sp., <i>Candida</i> sp., <i>T. pullulans</i> , <i>L. fermentum</i> , <i>L. mesenteroides</i> , <i>Pichia stivicola</i> , <i>S. faecalis</i>	[29,44,52,59,63]
Uttapam	Rice ( <i>O. sativum</i> ) and urad dahl ( <i>Vigna mungo</i> ) (3:1)	<i>Lactobacillus pentosus</i> and <i>L. plantarum</i>	[15,64]
Selfroti	Rice ( <i>O. sativum</i> ) and wheat flour ( <i>Triticum aestivum</i> ) (3:1)	Lactic acid bacteria like <i>L. mesenteroides</i> , <i>Enterococcus faecium</i> , <i>Pediococcus pentosaceus</i> , and <i>Lactobacillus curvatus</i> , <i>S. cerevisiae</i> , <i>Saccharomyces kluyveri</i> , <i>D. hansenii</i> , <i>Pichia burtonii</i> , and <i>Zygosaccharomyces rouxii</i>	[31,44,65]
Babru	Rice flour ( <i>O. sativum</i> )	<i>S. cerevisiae</i> , <i>Debaryomyces</i> sp., <i>L. plantarum</i> , <i>L. lactis</i> , Gram-positive bacillus, etc.	[31,44]
Ambebi	Rice ( <i>O. sativum</i> ) and ragi ( <i>Eleusine coracana</i> )	<i>L. mesenteroides</i> , <i>L. fermentum</i> , and <i>S. faecalis</i>	[15,44]
Aldai and vada	Rice ( <i>O. sativum</i> ), lentils like chana dal ( <i>Cicer arietinum</i> ), moong dal ( <i>Vigna radiata</i> ), tur dal ( <i>Pisum sativum</i> ), and urad dal ( <i>V. mungo</i> ), etc.	<i>Pediococcus</i> sp., <i>Streptococcus</i> sp., and <i>Leuconostoc</i> sp.	[15,57]
Sour rice	Rice ( <i>O. sativum</i> )	Lactic acid bacteria like <i>Lactobacillus bulgaricus</i> , <i>Lactobacillus casei</i> , <i>Pediococcus acidilactici</i> , <i>S. faecalis</i> , <i>Streptococcus thermophilus</i> , <i>Microbacterium flavum</i> , and <i>Saccharomyces</i> sp.	[11,15,66,67]
Sez	Rice ( <i>Oryza sativum</i> )	<i>Bacillus</i> spp., <i>Saccharomycopsis fibuligera</i> , <i>Kluyveromyces maxianus</i> , and <i>Saccharomyces</i> sp.	[13,39,44]
Chitrou/uppam	Rice ( <i>O. sativum</i> ) and urad dahl ( <i>Vigna mungo</i> )	Lactic acid producing bacteria like <i>Bacillus</i> spp., <i>Pediococcus pentosaceus</i> , <i>Tetragenococcus halophilus</i> , and <i>L. plantarum</i> .	[66,68]
Anarshe	Rice ( <i>O. sativum</i> )	Not reported	[15]

pathways. For the preparation of rice batter (mixed with pulses), microbial fermentation leads to the formation of carbon dioxide and other gases inside the batter and makes the food spongy. The degree of fermentation depends on time, which again determines food taste, texture, appearance, aroma, and so on [20,53,54].

Rice beer preparation involves a three-step nonsynchronized fermentation process. Initially, amylolytic molds are grown, which contribute to the saccharification and liquefaction of rice [53,54]. It appears that starch is first split into limit dextrins by the action of  $\alpha$ -amylase, and later by the action of glucoamylase these fragmented oligosaccharides are hydrolyzed into glucose. Thereby, rice is decomposed and creates an anaerobic environment. This condition favors the growth of LAB and Bifidobacterium, and apart from lactic and acetic acid, they also produce different hydrolytic enzymes (catalyzed both nutrients and anti-nutrients) and various metabolites. Later, alcohol-producing yeast (*Saccharomyces cerevisiae*) is grown, which enriches the ferment with various vitamins, amino acids, etc., and aids specific flavor and aroma [54]. During beverage fermentation, synchronized participation of different groups of symbiotic aerobes and anaerobes that float or embed within the matrix of cereal completely decomposes it into a simpler form for rapid assimilation through the gastrointestinal tract and favors maximum energy extraction. Thus, fermented beverages confer more health promoting attributes than solid/semisolid fermented foods.

## 6. Some popular indigenous rice-based fermented foods and beverages in India

### 6.1. Traditional rice-based fermented foods

Rice and other cereals are mainly used for preparation of traditional fermented dishes. However, the proportions and preparation process for all these fermented foods vary place to place [15,53,54]. The basic process starts with batter preparation, which is a thick to semisolid paste of raw ingredients mixed with other supplements. This is fermented either naturally or by starter for varied time periods. Microbial fermentation alters the quality of batter, improves the nutrient pool, and creates food-specific changes [55–57]. The fermented batter is then processed as per different food preparations like steaming, frying or baking, whereas some food items are consumed directly after the fermentation. The entire process is unique and followed dreamily to give the flavor, aroma, texture and taste. The final consumption of fermented foods is associated with side dishes like chutneys, curries, snacks, raw vegetables, etc. [58]. The information like raw materials, associated microbes, preparation process, nutritional details and health impacts of some popular and indicative rice-based fermented foods have been described below, as well as in Table 1.

#### 6.1.1. Idli

The savory cake *idli* is one of the most widely acceptable cereal pulse-based naturally fermented foods on the Indian subcontinent, particularly in South India [15]. This rice cake is a low-caloric starchy and nutritious foodstuff consumed mostly as a breakfast item. The ingredients are cereal rice (*Oryza sativum*) and the legume black gram dhal (*Phaseolus mungo*). Washed polished rice and black gram dhal are soaked separately in drinking water overnight and ground. Slurries of rice and black gram dhal are mixed to form a thick batter. The batter is kept overnight at room temperature for fermentation. Then, the fermented batter is placed into a concaved *idli* pan for steaming, finally yielding the savory spongy cake *idli* [44].

The batter formation is an acidic fermentation process mediated by a mixed culture of LAB, the major groups of which are

*Leuconostoc mesenteroides*, *Lactobacillus delbrueckii*, *Lactobacillus fermenti*, *Lactobacillus lactis*, and *Streptococcus faecalis*. Other organisms are *S. cerevisiae*, *Pediococcus cerevisiae*, *Debaryomyces hansenii*, *Hansenula anomala*, *Torulopsis candida*, and *Trichosporon beigelii* [44,59,60].

*Idli* contains approximately 3.4% protein, 20.3% carbohydrate, 70% moisture, 1% verbasco, 0.2% stachyose, and raffinose. Fermentation increases levels of amylase, proteinase, total acids, batter volume, soluble solids, essential amino acids (lysine, cysteine, and methionine), nonprotein nitrogen, soluble vitamins (folate, vitamin A, vitamin B1, vitamin B2, and vitamin B12) content, with reduction in antinutrient phytic acid [59,61].

*Idli* is generally regarded as antiobesity and used in weight losing diet. It is useful to reduce the risk of cardiovascular diseases, high blood pressure, and stroke. It is also used as a dietary supplement to treat children suffering from protein calorie malnutrition and kwashiorkor. Micronutrients like iron, zinc, folate, and calcium prevent anemia and facilitate the oxygenation of blood and nourishment of muscle and bone. The carbohydrate as well as dietary fiber content promotes healthy digestion and formation of bulky stools [15,60].

#### 6.1.2. Dosa

*Dosa* is a crispy flat thin pancake which is most popular throughout India. It tastes like crunchy wraps with inside vegetable fillings and is consumed as breakfast, dinner or sometimes as snacks. This recipe is traditionally made with rice (*O. sativa*) and lentils (*Phaseolus mungo*). The raw ingredients are soaked and ground separately with added water to get a smooth consistency. The raw ingredients are soaked and ground separately with added water to get a smooth and consistent batter. The batter is allowed to ferment overnight at room temperature. The colloid fermented batter is spread in the form of a thin layer on a flat heated plate which is smeared with a little edible oil. Within a few minutes, a circular semisoft to crisp *dosa* is formed [15].

LAB like *L. mesenteroides*, *S. faecalis*, *T.*, *Lactobacillus fermentum*, *Bacillus amyloliquefaciens*, *L. lactis*, *L. delbrueckii*, and *Lactobacillus plantarum* are predominant groups which participate in *dosa* fermentation. Minor groups related to yeasts, belonging to *S. cerevisiae*, *D. hansenii*, *T. beigelii*, *Torulopsis* sp., and *Trichosporon pullulans* [15,44].

*Dosa* fermentation increases in amount of total acids, total volume, total solids, nonprotein nitrogen, free amino acids, amylase, proteinases, vitamin B1, vitamin B2, folic acid, amino nitrogen, formation of diols, and antimicrobial and antioxidant substances. Antinutrients are reduced and enhance the bioaccessibility of zinc and iron [62].

*Dosa* is considered as an appropriate vegan diet for individuals with wheat allergies or gluten intolerance. Low glycemic load and glycemic index of *dosa* help to fight against prediabetic and post-diabetic conditions. It offers adequate energy for prolonged physical endurance. Some people believe that *dosa* has medicinal properties and can be used to increase fertility, weight of fetus, and breast milk. It is also considered as a remedy for rheumatism and neural disorders [15,62].

#### 6.1.3. Dhokla

*Dhokla* is a soft, spongy, and acid fermented cake very popular in Southern and Western India. It is generally consumed as a breakfast item. Rice (*O. sativa*) and Bengal gram dhal (*Phaseolus mungo*) are the main raw materials. Sometimes, people add chopped leafy vegetables to make it more palatable. Initially, thick batter is prepared from the raw materials and allowed to ferment overnight at room temperature. The fermented batter is poured into the greased tray and placed in the steamer in open conditions.

The spongy formed cake with a quite high water content is *dhokla* [29,44].

Yeasts like *Torulopsis* sp., *Candida* sp., and *T. pullulans* are responsible for a rise in the batter volume and sponginess. The dominant LAB present in *dhokla* are *L. fermentum*, *L. mesenteroides*, *Pichia silvicola*, *S. faecalis*, etc. [29].

Each serving of *dhokla* (213 g) contains 384 cal, 59 g of carbohydrate, 6.6 g of free sugars, 10.6 g of dietary fiber, 11.7 g of protein, 11.8 g of fat, 89 mg of sodium, 551 mg potassium, an adequate amount of calcium, iron, folic acid, vitamin A and vitamin C, and is free from cholesterol [52].

*Dhokla* has a low glycemic index (34.96) and is very useful for diabetic patients. It helps to reduce blood cholesterol, body weight, and protects from cardiovascular diseases [59,63].

#### 6.1.4. Uttapam

*Uttapam* is a thick slightly crisp pancake consumed as a palatable and pleasant breakfast or lunch which is popular mainly in South India. Traditionally, the *uttapam* is prepared from rice and urad dahl (*Vigna mungo*) in the proportion of 3:1. Batter prepared from the soaked raw materials is fermented at room temperature for 5–6 hours. The fermented batter is spread over a buttery/greased pan into a round shape. Toppings like chopped vegetables, paneer, capsicum, and onion are added over the flat batter and cooked in a low flame [15].

The microbes associated with fermentation are LAB and yeast. Saraniya and Jeevaratnam [64] isolated *Lactobacillus pentosus*, *L. plantarum*, *L. plantarum* sp., and *L. plantarum* sp. from *uttapam* batter. All organisms show probiotic characteristics as they survive in bile, gastric, and intestinal conditions, produce  $\beta$ -galactosidase, phytase, pectinase, and bile salt hydrolase, inhibit the growth of pathogens, and are able to adhere on Caco-2 cell surface. *Uttapam* is a zero trans-fat fermented food having approximately 160 Cal per 50 g serving, 0.4 g of fat, 34 g carbohydrate, 3.0 g dietary fiber, 5.0 g of protein, with source calcium, ferrous, vitamin A and vitamin C [15,64].

Being a cholesterol-free food item, *uttapam* is a prescribed food for high sugar and cholesterol patients. It is easily digestible and can reduce body weight and prevent obesity [64].

#### 6.1.5. Selroti

*Selroti* is very popular ethnic rice-based fermented product consumed with almost every meal by dwellers of hill areas in Himachal Pradesh, Sikkim, Darjeeling, Nepal, and Bhutan. Traditionally preparation starts with the batter which is prepared using rice and wheat flour, sugar, butter or fresh cream, and spices. It is kept for fermentation at room temperature for 3–4 hours. After that, it is deep-fried into ring shapes (golden brown in color) yielding spongy (breadlike) and pretzel like food items and served with potato curry, pickle, and meat [31,44].

The microbes associated with *selroti* batter fermentation are lactic acid producing microbes like *L. mesenteroides*, *Enterococcus faecium*, *Pediococcus pentosaceus*, and *Lactobacillus curvatus*, *S. cerevisiae*, *Saccharomyces kluyveri*, *D. hansenii*, *Pichia burtonii*, and *Zygosaccharomyces rouxii* [31,65].

*Selroti* is a gluten free and trans-fat free food item. An average serve of 260 g *selroti* gives approximately 694 Cal, 138.0 g carbohydrates, 8.4 g proteins, 14.8 g fat, 42.0 g sugars, and 2.68 g dietary fibers. Minerals like sodium, potassium, iron, calcium, and vitamin A and vitamin C are also present in *selroti* [31]. *Selroti* is generally offered for good health and a recommended diet for protecting dyslipidemia and cardiometabolic risks [65].

#### 6.1.6. Babru

*Babru* is partially fermented rice-based food and is very popular among the people of the Lahaul and Spiti regions in Himachal



Pradesh. The sweet taste, flat, spongy, and savory delicacy of *babru* is associated with the cultural traditions of people. Rice flour is the main raw material which is made into semisolid paste by adding water (2:1) and kept at room temperature for 3–4 hours for fermentation. Next, the fermented batter is cooked as a flat pancake with edible oil until it becomes spongy [31]. The microbial compositions in the *babru* are mainly yeast and LAB, like *S. cerevisiae*, *Debaryomyces* sp., *L. plantarum*, *Lactococcus lactis*, etc. [31].

The nutritive value of *babru* has not been evaluated, but it is supposed to be an easily digestible carbohydrate-based delicious diet. Normally *S. cerevisiae* improves aroma (flavor), digestibility, and nutritive value of food. The edible LAB make food acidic and also show many therapeutic, nutritive, and probiotic properties [31,44].

#### 6.1.7. Ambeli

*Ambeli* is a rice (*O. sativa*) and ragi (*Eleusine coracana*)-based fermented food preferred as a breakfast meal by the people of Central India. For its preparation, ragi flour is made into thick slurry and allowed to ferment at room temperature for 14–16 hours. Then, partially cooked rice is mixed with it and cooked further. After cooling to room temperature, sour milk is added to prepare *Ambeli*. The microbes associated with the *ambeli* fermentation are *L. mesenteroides*, *L. fermentum*, and *S. faecalis* [15].

*Ambeli* is a low calorie fermented food and approximately 250 mL has 115 Cal, 1 g total fat, sodium 60 mg, total carbohydrate 20 g, and sugars 10 g. This is considered as an easily digestible protein rich food and suitable for infants as well as adults [15,44].

#### 6.1.8. Adai and vada

*Adai* and *vada* are traditional South Indian fermented dishes which are prepared using rice, lentils, and other seasoning vegetables. The traditional process starts with the batter preparation using rice and lentils. After fermentation, the batter is fried with some edible oil in a flattened donut shape. Sometimes the batter is mixed with spices like red chillies, fresh peppercorns, cumin, ginger pieces, green chillies, fresh coriander leaves, coconut pieces, etc., to give a piquant flavor to *adai* and *vada* [15].

Fermentation is assisted by predominant bacteria like *Pediococcus* sp., *Streptococcus* sp., and *Leuconostoc* sp. These are low calorie protein and iron rich foods. They have 197 Cal, 505 g fat, 20 mg sodium, 350 mg potassium, 39.6 g total carbohydrates, 6.5 g dietary fibers, 1.7 g sugars, and 7.6 g proteins and contain 2% vitamin C, 3% calcium and 14% iron. This is considered as a healthy snack as it is rich in proteins, iron, and dietary fibers. This is recommended for children as well as women for the health benefits [57].

#### 6.1.9. Sour rice

Sour rice is popularly known as *poita bhat* in Assam, *panta bhat* in Bengal, and *pokhalo* in Odisha, and is generally consumed during lunch and breakfast [11,15]. The principal raw ingredients are rice

and water. Sometimes *dahi* (Indian yogurt), salt, spices, and leafy vegetables are also added to increase taste. The cooked rice is cooled down to room temperature and adequate water is added to it. This watery rice is allowed to ferment overnight at room temperature. The fermented rice with water is consumed along with cooked vegetables/other ingredients [15].

The fermentation is associated with LAB like *Lactobacillus bulgaricus*, *Lactobacillus casei*, *Pediococcus acidilactici*, *S. faecalis*, *Streptococcus thermophilus*, *Microbacterium flavum*, and *Saccharomyces* sp. The fermentation process is known to increase the amounts of vitamin B complex, and vitamin K. About 100 g of sour rice contains 73.91 mg iron, 303 mg sodium, 839 mg potassium, and 850 mg calcium [66].

Fermented sour rice is a high energy rich, body rehydrating food. It controls bowel movement as well as fiber release in the stool, and prevents constipation. The fermented rice restores healthy intestinal flora and can prevent gastrointestinal ailments like duodenal ulcers, infectious ulcerative colitis, Crohn's disease, irritable bowel syndrome, celiac disease, candida infection, etc. [66,67].

#### 6.1.10. Sez

*Sez* is a popular rice-based festive food prepared by Bhotiyas and other communities in Himachal Pradesh. Traditionally, starter (*balam*) is used for *sez* preparation [13]. *Balam* is prepared with old starter, spices, and different plant parts. Initially, starter is mixed with the cooked rice and kept in an air sealed wooden or earthenware container in a dark and cool place. The anaerobic fermentation takes place for at least 24 hours and semifermented rice is consumed as *sez* [39]. The fermentation process may involve the saccharolytic and ethanol producing microbes which are responsible for starch to alcohol bioconversion. This is served as snacks with some spicy chutneys [44].

#### 6.1.11. Chitou/appam

Both *chitou* and *appam* are rice-based traditional flat culinary pancakes and are popular in the Odisha and Kerala states. In Odisha, *chitou* is a delicious festive dish, whereas *appam* is regular food item in Kerala. The varying proportions of parboiled rice and black gram (*Vigna mungo*) are used for the preparation of *chitou* and *appam* in varying seasons. Conventionally, parboiled rice and urad dahl paste are mixed to prepare the batter which is fermented overnight. The fermented batter is next mixed with sugar, grated coconut, or other seasonings. The final mixture is poured into an earthen mold, covered, and fried in low heat to obtain traditional *chitou* and *appam* [66,68]. Both the *chitou* and *appam* fermentations are acidic in nature, which is supposed to be due to lactic acid producing bacteria. The details of microbial composition in the batter have not been explored.

*Chitou/appam* can give 138.8 Cal, 3.7 g total fat, 0.1 g unsaturated fatty acids, 31.7 mg sodium, 13.5 mg potassium, 23.2 g total

**Table 2**  
Description of some popular rice-based fermented cakes (*pitha*) in India [68].

Fermented cake (pitha)	Specialty	Raw material	Shelf-life (d)	Microorganisms involved
<i>Chakuli</i>	Dosa-like round shaped flattened pancake	Rice ( <i>Oryza sativa</i> ) and black gram dhal ( <i>Phaseolus mungo</i> )	1	Not reported
<i>Enduri pitha</i>	Steamed flavor cake	Rice ( <i>O. sativa</i> ) and black gram dhal ( <i>P. mungo</i> )	2	<i>Lactobacillus plantarum</i>
<i>Munha pitha</i>	Spongy and served by cutting into pieces	Parboiled rice ( <i>O. sativa</i> ) and black gram dhal ( <i>P. mungo</i> )	1–2	Not reported
<i>Chhuchipatra pitha</i>	Sweet taste, square shaped, pizza-like appearance	Parboiled rice ( <i>O. sativa</i> ) and black gram dhal ( <i>P. mungo</i> )	2	Not reported
<i>Podo pitha</i>	Slightly burnt outer cover, spongy soft inside	Parboiled rice ( <i>O. sativa</i> ) and black gram dhal ( <i>P. mungo</i> )	2–3	Not reported

carbohydrate, 1.1 g dietary fiber, 2.1 g protein, with vitamin A, B-complex, calcium, folate, iron, niacin, riboflavin, and thiamine. This is a healthy and easy digestible, nutritionally enriched food [66].

#### 6.1.12. Anarshe

Anarshe is a gluten-colloid type fermented food and traditionally used by the people of Sikkim and Himalayan India. The golden colored crumbled snack, *anarshe*, is generally used during *Diwali* festivals and Maharashtrian *fara*. The traditional process of *anarshe* preparation starts with cooked polish rice which is used for dough preparation with addition of the starter, *marcha*. The dough is allowed to ferment in airtight conditions at room temperature for 3–4 days. Afterwards, the ripened dough is made into medium thick shaped puri and deeply fried into edible oil [15]. The LAB and yeasts like *H. anomala* and *Mucor rouxianus* are the predominant microbes participating in the fermentation of dough [15].

#### 6.1.13. Fermented rice cake (pitha)

The people in the states of West Bengal, Odisha, Jharkhand, and Bihar prepare a variety of rice cakes, locally called *pitha*, specially prepared during festivals and rituals. These foods are prepared and consumed by all the communities irrespective of caste and creed due to their nutritional value, pungent taste, flavor, and aroma. These foods are produced from the fermented rice and rice-legume batters, which are shaped and optionally filled with sweet or savory ingredients. For this preparation, rice is the main ingredient, which is soaked in water for 8–12 hours, air dried and then ground in to fine flour with the help of a traditional grinder. Sometimes, boiled rice is also added to make the *pitha* [68]. All of these foods are delicious and easily digestible, and also suitable for ailing persons, prenatal or postnatal women, and children. These *pithas* are unknown to the nutritionists and entrepreneurs due to lack of their scientific exploration (Table 2).

#### 6.1.14. Chakuli

This is a *dosa* like round shaped flattened pancake generally prepared with rice (*O. sativa*) and black gram dhal (*Phaseolus mungo*). The coat free black gram and rice flour batter are kept for 10–12 hours for fermentation and then fried over a hot greased pan. This has a 1 day shelf life and is usually served hot. The microbes that participate in the fermentation process are unknown [68].

#### 6.1.15. Enduri pitha

Enduri *pitha* is the steamed flavor cake which is prepared from rice and black gram dhal. For this preparation, fermented batter of black gram and rice flour are filled in to folded leaves of turmeric (*Curcuma longa* L.) and then cooked over steam. It has a 2 day shelf life and *L. fermentum* is known to assist in fermentation. This helps in strengthening the immune system, fighting against worms, and different infections which are common in the winter season [68].

#### 6.1.16. Munha pitha

Munha *pitha* is a spongy fermented cake which is prepared using parboiled rice powder and black gram dhal. The batter is prepared using flour and subjected to brief fermentation. An adequate amount of batter is placed on a piece of cloth which is tied over the mouth of an earthen pot half filled with water, and then steamed until it loses its stickiness. It has a shelf life of 1–2 days, and is a delicious and stomach filling food [68].

#### 6.1.17. Chhuchipatra pitha

This is a square shaped, sweet tasting, pizza like fermented *pitha*. Generally, the batter is prepared using parboiled rice and black gram dhal and fermented with the addition of inoculum curd. Like *chakuli*, the batter is half-fried as a thin smear using a spatula

over a hot greased pan. Then coconut, curd, cheese, and sugar are placed in the center position and folded in a square shape to fry suitably. It has a shelf life of 2 days and is a nutritious, palatable, and delicious item [68].

#### 6.1.18. Podo pitha

This fermented cake has a slightly burnt outer cover with a white spongy soft inside. Parboiled rice and black gram dhal are used for the batter preparation and fermented briefly (2–4 hours). The fermented batter is mixed with different sweeteners and coconut, then wrapped with banana (*Musa paradisiaca* L.) or sal (*Shorea robusta*) leaves and roasted in an oven or earthen oven with the help of charcoal to bake in a low but continuous heat for 5–10 hours. The low water content *pitha* has a shelf life of 2–3 days and is an energy rich cake containing abundant carbohydrates, free sugars, and fibers [68].

### 6.2. Ethnic rice-based fermented beverages

Rice-based beverages or rice beer are rare types of food products, only found in a few tropical areas of Asia-Pacific countries in contrast to alcoholic beer from barley malt in Western countries. Traditional beverages have different appearances which vary from crystal-clear products to turbid liquid or thick gruels and pastes. Air dried cooked rice powder is the principal substrate and traditional starter tablet/dust is used for the preparation of different varieties of beverages [31]. The use of selective plant parts for preparation of starter is a unique ancient culture in the Indian subcontinent [26]. Diverse groups of microbiota from plant origin as endophytic organisms are the functional microbes for mixed culture and multistage fermentation of rice, which is not possible by using old ferments. Apart from this, herbal products are good sources of therapeutic and preservative metabolites that add extra flavor to the rice-based fermented products [13]. A comprehensive list of fermented beverages popular in the Indian subcontinent is depicted in Table 3. The process of rice fermentation involves a two-stage fermentation: solid state fermentation wherein molds grow on raw material and are saccharified and gelatinized; and thereafter, semiliquid substrate favors the growth of LAB and alcohol producing yeast. The associations of different groups of microbes and their relative concentrations are essential for the development of acceptable sensory quality of a traditionally fermented food [36,53]. The final fermented, undistilled beverages are consumed directly, and usually contain enormous amounts of health-beneficial components, probiotics, and a small quantity of alcohol [70].

#### 6.2.1. Haria

Haria is prepared using boiled scorched rice which is mixed with *bakhar* (1:100), transferred to an earthen pot, and kept in a dark room for 3–5 days for fermentation. It is diluted with water and sieved to get the *haria*. This is known to protect from gastrointestinal ailments like dysentery, diarrhea, amebiasis, acidity, and vomiting. It exerts a significant level of antioxidant activity [26,53,54].

#### 6.2.2. Apong

Apong is prepared using a mixture of ash of paddy husk and straws, cooked glutinous rice, and traditional starter, *epop* (1:30) and transferred into an earthen pot. It is allowed to ferment for 20 days at 30–35°C. The ferment is filtered to get a clear brownish filtrate *apong*. It is a nutritious, energy-rich refreshing drink with antimicrobial, antioxidant, and other age preventing effects. *Apong* is also helpful in preventing the formation of kidney stones [8,71].

#### 6.2.3. Jou

Jou preparation is started by mixing the air dried cooked rice with starter *amao* (1 cake per 1 kg of rice) along with three to four

**Table 3**

Presentation of traditional fermented beverages with the raw ingredients, microbial profile, and products nutrition.

Name of beverage	Origin	Raw materials	Starter based/natural	Scientific exploration		References
				Microorganisms	Nutrients	
<i>Haria</i>	East central India (West Bengal, Orissa, and Jharkhand)	Low grade scorched rice	<i>Bakhar</i> (microbes + plant residues)	<i>Saccharomyces cerevisiae</i> , lactic acid bacteria like <i>Lactobacillus fermentum</i> , <i>Bifidobacterium</i> sp.	pH 3.61, alcohol 3–4% (v/v), maltooligosaccharides, pyranose sugar derivatives	[26,53,54]
<i>Apong</i>	North-east India (Assam and Arunachal Pradesh)	Rice, ash of paddy husk and straw	<i>Ipoh</i> or <i>epop</i> (plant parts + old ferments)	<i>S. cerevisiae</i> , <i>Hanseniaspora</i> sp., <i>Kloeckera</i> sp., <i>Pischia</i> sp., and <i>Candida</i> sp.	pH 4.06, lactic acid 0.5%, carbohydrate 46 mg/mL, reducing sugar 3 mg/mL, protein- 1.05 mg/mL, free amino acids 2.43 mg/mL, ethanol 7.52–18.5%, amylase 2.4 U/mL	[8,71]
<i>Jou</i>	North-east India	Cooked boiled rice	<i>Amao</i> or <i>angkur</i> (microbes + plant parts)	<i>S. cerevisiae</i>	pH 2.0, carbohydrate 48 mg/mL, reducing sugar 3 mg/mL, protein 1 mg/mL, free amino acid 3 mg/mL, total acidity 1.48%, alcohol 18% (v/v)	[8]
<i>Judima</i>	North-east India	Glutinous variety of rice	<i>Umhu</i> or <i>humao</i> (rice + plant parts)	<i>Pediococcus pentosaceus</i> , <i>Bacillus circulans</i> , <i>Bacillus catarosporous</i> , <i>Bacillus pumilus</i> , <i>Bacillus firmus</i> , <i>Debaryomyces hansenii</i> , <i>S. cerevisiae</i>	pH 4.4, titratable acidity 0.45%, carbohydrate 32 mg/mL, protein 0.97 mg/mL, free amino acids 3.21 mg/mL, ethanol 16% (v/v), trace elements like Cu, Cr, Mn, Fe, K, Na, Se	[72,73]
<i>Zutho</i>	Nagaland	Rice flour	<i>Khekhrii</i> or grist (dust of sprouted unhulled rice)	<i>S. cerevisiae</i> , <i>Rhizopus</i> sp.	pH 3.6, acidity 5.1 mL, reducing sugar 6.3 mg/mL, total sugar 39.7 mg/mL, ethanol 5% (v/v)	[8,74]
<i>Bhaati jaanr</i>	North-east India	Glutinous rice	<i>Marcha</i> (rice dust + plant parts + old <i>marcha</i> )	<i>Hansenula anomala</i> , <i>Rhizopus</i> spp., yeasts, <i>Pichia</i> spp., lactic acid bacteria, <i>Pediococcus</i> and <i>L. bif fermentous</i>	pH 3.5, alcohol 5.9% (v/v), ash 1.7%, protein 9.5%, fat 2.0%, crude fiber 1.5%, carbohydrate 86.9%, food value (per 100 g) 404.1 kcal, trace elements like Ca, K, P, Fe, Mg, Mn, Zn.	[69]
Rice <i>Jann</i>	Uttaranchal and Himachal Pradesh	Rice	<i>Balam</i> or <i>balma</i> (microbes + plant parts)	Not reported	<i>Jann</i> is known to be enriched with ethanol (< 10% v/v), carbohydrates, amino acids, minerals, and vitamins.	[39]



pieces of chilli and charcoal, then transferred to an earthen pot. Fermentation continues for 3–5 days. The ferment is diluted and filtered for consumption. The Boro tribe consumes this as a refreshing drink and it has a significant role in their sociocultural events. *Jou* is a popular refreshing drink which keeps the body relaxed and is known to prevent jaundice and urinary disorders [8].

#### 6.2.4. *Judima*

The fermented beverage *judima* is prepared through mixing the starter powder *humao* with air dried boiled rice (1:100) and leaving to ferment at room temperature. After 3–4 days of fermentation, the mixture is transferred to *khulu* (a triangle shaped bamboo cone) and the pale to dark yellow colored leachate *judima* is collected. It has antiinflammatory, antiallergic, antioxidant, antibacterial, antifungal, antispasmodic, hepatoprotective, hypolipidemic, neuroprotective, hypotensive, antiaging, and antidiabetic potentialities [72,73].

#### 6.2.5. *Zutho*

For *zutho* preparation, cooled rice porridge is mixed with grist and poured into an earthen jar. The mixture is allowed to ferment for 2–3 days. After fermentation, the *zutho* has formed and is drunk directly. This is known to boost the immune system, lower the blood insulin level, prevent loss of appetite, lower bad cholesterol, assist in wound healing, and prevent infection [8,74].

#### 6.2.6. *Bhaati jaanr*

Starter powder *marcha* (2%) is mixed with cooked air dried glutinous rice and kept in a vessel at room temperature for 2–8 days. A thick paste is made by stirring the ferments and consuming directly as *bhatti jaanr*. It is consumed as a staple food or mild alcoholic sweet tasting beverage. It is recommended for ailing persons and postnatal women to regain their physical strength [69].

#### 6.2.7. *Rice jann*

*Rice jann* is a popular fermented rice beverage in the cold high altitude area. For preparation, the starter *balam* is mixed with cooled boiled rice (1:125) and stored in an airtight earthen pot for 6–10 months at room temperature. The fermented *jann* is then diluted, filtered, and consumed. This is considered as a very energy rich refreshing drink and known to provide protection against cold [39].

### 6.3. Functional metabolites in folkloric rice-based fermented foods

According to Roberfroid [75], a food product can be made functional by: (1) eliminating a component known to produce a deleterious effect when consumed (an allergenic protein, lactose, phenylalanine); (2) by increasing the concentration of a component naturally present in food to a point at which it will induce predicted effects (fortification with a micronutrients); (3) increasing the concentration of a nutritive component to a level known to produce beneficial effects; (4) adding a component that is not normally present in most food and is not necessarily a macronutrient or micronutrient, but for which beneficial effects have been shown (nonvitamin antioxidants or prebiotic fructans); (5) replacing a component, usually a macronutrient, the intake of which usually causes deleterious effects; or (6) increasing bioavailability or stability of a component known to produce a functional effect or to alleviate the disease risk potential of the food. Being the largest choice of food ingredient globally, rice has been found to contain > 5,000 small metabolites [76]. The processing of rice into various edible food items could change the profile of metabolites. During milling particularly, the reduction of antioxidant compounds was observed to be 70–87% from the red rice and about 50% from the white rice. Milling also reduced

the level of tocopherols,  $\gamma$ -oryzanol, and ferulic and sinapic acids [77]. In a separate study, > 3,000 small metabolites only have been detected after the cooking of rice [78]. There are large numbers of evidences indicating the bioenrichment of rice with different reactive metabolites occurring during fermentation. Considering these types of scattered evidences, a scientific link or correlation is very essential to focus on the specific metabolic pathway. Metabolomics is a cutting edge comprehensive analytical platform for low molecular weight compounds in various biological samples; it can provide a high throughput and sensitive approach to assess the outcome of different metabolites in the food and beverages. The technique can be a potent tool to predict the dynamics and interconversion of rice metabolome during fermentation. Thus, there is huge scope for the incorporation of systems biological approach to reveal the nutritionally important rice metabolites improves in various rice-based fermented foods and beverages.

The changes of metabolite composition in the final rice-based fermented products are related with the participating microbiota and nature of fermentation [53]. Rural folk unknowingly used microbes in primitive ways for the preparation of different types of food, which were enriched with unexplored metabolites, but these serve as major sources of energy, nutrients, and health-beneficial components. Most of these metabolites exert various health impacts, demonstrate protective activities over human diseases, and also manifest beneficial effects on the immune system [79]. For these reasons, tribal gurus (native physicians) prescribe them to cure different degenerative and infectious diseases. After fermentation, rice becomes enriched with various metabolites, some notable examples like phenolics (monophenols and polyphenols), flavonoids (mono-C-glycosides, malonylated O-hexosides, O-glycosides), vitamin E (tocopherols and tocotrienols), phytosterols, linolenic acid, anthocyanins, proanthocyanidins,  $\gamma$ -oryzanol, etc. [80]. The bioavailability of phenolics in rice is related with the increase in efficiency of donating hydrogen atoms to reactive oxygen radicals, which is a mechanism of anticancer activity. For example, rice bran fermented with *Saccharomyces boulardii* has the potential to reduce the growth of human B lymphomas. Its lipid-soluble metabolites, like tocopherol and tocotrienols, are known to induce an antiinflammatory cell signaling process [81,82]. However, the reduction of several detrimental metabolites like phytic acid, polyphenols, trypsin inhibitor, etc., is related to its digestibility improvement [83]. Phutthaphadoong et al [84] noticed that the fermented brown rice and rice bran gained some chemopreventive potentialities, as it can suppress the carcinogenesis of the colon, liver, stomach, bladder, and esophagus. Fermentation of germinated rice with probiotic organisms makes it healthy food with natural fibers,  $\gamma$ -aminobutyric acid, and inositol hexaphosphate [61]. The nutrient and biochemical basis of a local rice beer, called *haria*, has extensively studied by this author group [26,53,54]. This beverage is energy rich and exerts many health-beneficial impacts. During fermentation, it accumulates different maltooligosaccharides (G5–G2), such as maltotetraose (G4, 20.1  $\mu$ g/g), maltotriose (G3, 28.1  $\mu$ g/g), and maltose (G2). These are low in calories, inhibit the growth of intestinal pathogens, and are very nutritious for infants and aging people [53]. A number of pyranose derivatives like 2,3,4,5-tetra-O-acetyl-1-deoxy- $\beta$ -D-glucopyranose,  $\beta$ -D-mannopyranose pentaacetate,  $\beta$ -D-galactopyranose pentaacetate, and 1,2,3,6-tetra-O-acetyl-4-O-formyl-D-glucopyranose are also accumulated, which have profound immune-stimulatory, antioxidant, and antimutagenic activities. In addition, a number of oligosaccharides, phenolics, and flavonoids in the rice beer show significant free radical scavenging activities, which can potentially reduce the risk of cardiovascular and other degenerative diseases [53,54].

## 7. Conclusion

Malnutrition and poor health are the major burdens in the developing as well as underdeveloped countries. Although India is the major producer of cereals, the raw cereal-based foods are not enough to combat against health related issues, as these have some inherent nutritive limitations, particularly swelling of their starch content upon cooking, a limited quantity of essential amino acids, and a limited bioavailability of mineral content (5–15%) due to the presence of phytic acid and other antinutritional factors. The fermented rice-based food formulation may be the God's gift, as this improves the overall nutritive capacity and has an added advantage of physiological functions. The traditional cofermentation of rice with other cereals, leguminous seeds, or herbs can further improve the amino acid and mineral profiles, and therapeutic potentialities, on account of complementary actions. Further, the wet processing of cereals with mixed culture fermentable organisms (LAB and yeast) improves fortification (minerals and nutrients), energy density, and dephytinization. A review by Nout [21], considering these indigenous practices. India has a rich diversity of fermented foods, however, most of these food practices are regional and mostly confined within a specific community. The large diversity of Indian rice-based foods and beverages has the potentiality of being enriched resources for functional food development [19,29,85]. Proper scientific intervention of current folkloric rice-based foods and beverages can explore the gastronomic portrait of novel and bioactive nutraceuticals, therapeutic probiotics, healthy metabolites, and peptides, so that these foods will be exploited as functional and healthy food for the world community. The standardization of process parameters and the adaptation of newer technologies for fermentation of rice by mixing with other cereals, considering acceptability by the end users, are also essential to improve individual nutritional status as well as community health.

## Conflicts of interest

The authors have no conflicts of interest to declare.

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